Energy Productivity in the Industrial Sector: An Econometric Analysis

J. M. Roop

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SUMMARY AND CONCLUSIONS

This study examines aspects of energy productivity and energy intensity within the industrial sector of the economy. Our results suggest that relative prices and other economic factors can explain much of the variation in both energy productivity and energy intensity for manufacturing and mining and for the industrial sector as a whole. Cyclical factors, seasonal factors and trend variables are also useful in explaining variation in these data, both for annual and monthly time series. Of the variables examined, it appears that the relative price of energy is a highly significant factor in accounting for the difference between actual industrial energy intensity and that which might have been expected had pre-1973 trends continued.

But these findings tell only a small part of a larger story. There is consistent evidence, statistically, that these relationships are not adequately specified. And this finding is further supported by a review of the literature. At the same time that relative energy prices were rising sharply, many other events were simultaneously occurring that could cause multiple interpretations of the same data--price controls were being eased, requirements for pollution abatement investments were being promulgated, multinational companies were shifting production to lower-cost countries, to name but a few of these compounding factors. Moreover, our results are descriptive, at least in part, rather than causal. Although rising energy prices likely caused some of the changes that occurred, how these changes were brought about requires that we pursue the analysis at the level of the economic agent making the decision, rather than relying on descriptive analyses of changes that occur.

Viewed from this perspective, energy productivity could change as a result of individual firms implementing more efficient practices or shifts in industrial output from less to more energy-efficient industries. This latter change could occur as a result of consumers' choice or through producers using less of those inputs that have a high energy component, or through the substitution of imports for industrial products with high energy content. The

choices of these economic agents would then also explain, at least in part, how energy intensity within the industrial sector had changed.

This is a topic for further research. The results of this study clearly suggest that such work needs to be done.

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1.0 INTRODUCTION

The major objective of this study is to estimate the relative importance of factors that influence energy productivity in the industrial sector of the economy--especially manufacturing and mining. Among these major factors, we have selected changing relative prices, investment, and cyclical/seasonal phenomena as variables of interest in explaining changes in energy productivity as measured by output-energy ratios. The impact of these factors is examined using regression analysis on both annual data from 1954 to 1980 and monthly data from 1973 to 1980. The focus is on two measures of energy productivity: an output-energy ratio that applies value-added weights to the index of output and this same ratio applying energy consumption measures as weights. Shifts in energy intensity of the industrial sector examined are measured by the differences between these ratios and the ratio of energy weighted to value-added weighted output. These further measures are indicators of the shift in energy intensity of industrial output.

Shifts in the energy intensity of industrial output may occur as a result of many factors. Among these are the growth in income and output, changing relative factor and final goods prices, competition from abroad, shifts of material-intensive industries to locations outside the country, seasonal factors, and changes in production technologies. This study concentrates on only three of these factors. Using annual data, the three factors are 1) the relative price of energy, 2) the cyclical influence of output growth represented by the level of capacity utilization, and 3) the influence of technological change as represented by the ratio of new investment to the total capital stock or a time trend. In the analysis that uses monthly data, the influence of technology is dropped, since its effects are neither very short term nor available on a monthly basis, and seasonal factors are substituted. These static regression analyses allow us to disaggregate the influence of each factor on different measures of energy intensity in the industrial sector.

The analysis begins by reviewing other studies to assess the measured causes of changes in energy intensity within the industrial sector. This

review indicates that little empirical work has been done that measures either the changes that have occurred or the causes of these changes. The third section begins the annual analysis; regression results that sort out the separate influences of three variables on different measures of output-energy ratios are reported. The fourth section then analyzes alternative measures of the change in energy intensity, using these same three factors. This analysis includes a decomposition of the separate influences of energy price changes, cyclical, and technological factors. The fifth section reports on the analysis of monthly measures of output-energy ratios. This section provides evidence on the magnitude of the seasonal factors that influence energy consumption. The final section gives our conclusions, and highlights research topics that need further study. An appendix describes the data used in the analysis.

2.0 LITERATURE REVIEW

In this brief review, our attention will focus primarily on studies that have some bearing on the questions addressed in this paper. Specifically, what factors are associated with changes in energy intensity within the industrial sector and how do these factors affect energy efficiency. Limiting the scope of these issues also limits the range of literature reported on, since few writers address these issues directly. But a side issue relating to one of these factors, namely energy prices, is integral to the discussion -- what is the approximate magnitude of the price elasticity of the demand for energy.

We take for granted that this elasticity is negative -- an increase in the price of energy causes a decline in the quantity demanded. Beyond this statement, the evidence is less than overwhelming. Yet this elasticity is important for assessing the sensibility of our results: if demand is inelastic (and most would agree it is), then sharp increases in price will have relatively less of an effect on demand. But by how much? We will return to this question later. We begin by first reviewing studies of industrial energy demand, which leads into the elasticity question. We conclude this section with a brief look at the macroeconomic studies that measure the impact of oil price increases on the economy as a whole.

A Department of Commerce study from the Bureau of Industrial Economics (BIE) by Kristensen and Correia (1980) examined eight 4-digit manufacturing industries that account for 60 percent of total manufacturing energy consumption, but only 8 percent of value added. They note that factors that affect energy efficiency can be either outside the control of the industry--cyclical fluctuations in demand, changes in product mix induced by demand, or changes required by legislative fiat--or subject to their control--elimination of waste, interfuel substitution, implementing new technologies and recycling scrap materials. The study covered the years 1971 and 1974 to 1977.

The general tenor of the study by Kristensen and Correia is that every industry has its special case. For example, paper and paperboard production shifted from recycled paper to virgin fiber final products, which are more energy intensive, as a result of shifts in demand. This shift occurred even

though the price of energy over this period rose substantially. But offsetting this, wood wastes have been increasingly substituted for purchased energy, thus raising the purchased energy efficiency of these industries. Fuel switching in cement, on the other hand, has reduced the energy efficiency of this industry since using the coal process requires more Btu's to produce the same amount of output.

On balance, these eight industries have increased their energy efficiency over the period 1971 to 1977. Although energy use increased 0.1 percent per year from 1971 to 1977, value added grew at a much faster rate (3.1 percent per year), so energy consumption per dollar of output declined 2 percent per year. This is less than for manufacturing as a whole (energy use per dollar of value added declined 3.2 percent per year) but greater than for the national economy as a whole (1.2 percent per year). These results are in close agreement with measures of energy efficiency reported by Belzer and Roop (1981).

Hirst et al. (1981) look at the role of improved energy efficiency in energy-use patterns since the sharp escalation of energy prices in 1973. In the industrial sector, energy consumption grew at the rate of 2.9 percent per year from 1950 to 1972; from 1973 to 1980, it grew at a rate of 0.4 percent per year. The energy-output ratio declined about 10 percent from 1973 to 1980, nearly double its historical rate. "This improvement in industrial energy efficiency is made up of two components; increases in energy efficiency of individual processes and changes in the composition of industrial output" (p. 28-29) Quoting Marlay (see below, p. 2.4), Hirst argues that about "half the reduction in 1980 energy intensiveness (relative to historical trend) was due to efficiency improvements and the remainder was due to changes in product composition." (p. 30)

The Hirst study asserts that 1980 industrial energy use was about 10 Quad less than it would have been had historical trends continued. Half of the reduction was due to slower economic growth, one-quarter to changes in the mix of industrial output and one-quarter to improvements in energy efficiency. Of the improvements in efficiency, about three-quarters was due to a continuation of historical trend, the remainder to additional improvements (see Hirst's Table 13). It is not clear how these numbers were arrived at, although there

is an explanation of how total energy demand was obtained. It is worth examining the method of Hirst and his associates, as reported in Hirst's Appendix B, since the work to follow takes a considerably different tack.

The decomposition of energy consumption used by Hirst et al. is based on a linear model that explains energy use as a function of GNP, energy prices and time (and sometimes a lagged dependent variable). In another variant of this equation, the energy-output ratio is a linear function of energy prices and time. Based on estimated coefficients from the latter version of the equation, a GNP growth rate of 4.2 percent and trend energy prices were substituted to determine baseline forecasts of energy consumption had trends continued. These trend projections use the estimated equation with the lowest energy price elasticities of all those reported in Hirst's Table B.2: $-.07$ (the range is from $-.24$ to $-.07$ with a mean of $-.13$).

There are a number of problems with this equation, not the least of which is the low energy price elasticity. Hirst notes that the Stanford Energy Modeling Forum reports a mean price elasticity of $-.5$. But there is additional evidence that the price elasticity is higher than that reported by Hirst. Berndt and Wood (1981) report price elasticities that range from $-.8$ to $-.3$, with an average elasticity of $-.58$. Magnus (1979) reports elasticities for the U.S. that range from $-.79$ to $-.49$. Anderson (1980) reports elasticity measures from $-.5$ to $-.42$ for work done by others, although he argues that when intermediate materials are properly taken into account, the elasticity drops to about $-.2$. So the preponderance of evidence suggests that the Hirst's estimates are too low. There are other difficulties with this simple model apart from the low price elasticity.

Economic theory suggests that demand for a commodity depends on its relative price, the relative prices of competing and substitute commodities, income and other variables that might influence taste. As best one can determine from Hirst's Appendix B.2, the demand for energy is a function of income (GNP), the absolute (not relative) price of energy, and time. Since substitution effects in both consumption and production are contingent on the relative price of energy, this formulation suffers from the use of an inappropriate price measure. (But in fairness, a plot of the relative prices

used in Section 4.1, compared with the Hirst prices, show only minor differences--smaller increases in 1976, a decline in 1978 for the relative prices, for example--but in a regression analysis, these differences might be critical.)

There are a number of other studies that have only little direct bearing on the questions addressed in this paper, but are mentioned in passing. Mork and Hall (1980a, 1980b) have expanded a small macroeconomic model with an energy sector to examine the policy questions related to response to sharp increases in exogenous energy prices. The major weakness of this model, and one which makes the results highly suspect, is that it is unstable. A more recent study by Darby (1982), looks at the output impacts of changing energy prices using a model that consists of several small macroeconomic models. He notes that determining the output effects in isolation is difficult since a number of other events were also occurring as prices rose. Darby concludes that further work needs to be done to determine how oil price shocks affect economies.

One author has made a significant contribution to the questions addressed in this report--Robert C. Marlay (1981a, 1981b, 1982). His contributions to this report are more than just indirect. The cautionary conclusion of Section 4.0 is a direct result of suggestions from Marlay (1982) and conversations with the author. More directly, the data used in this analysis and described in the Appendix comes directly from Marlay's unpublished dissertation research. The completion of this dissertation is expected, and, thus, the data will be available this summer.

3.0 ANALYSIS OF ANNUAL OUTPUT-ENERGY RATIOS

Econometric analysis of the output-energy ratios (OER) is based on the proposition that the ratios are behavioral functions of economic and noneconomic factors. A significant portion of the economic environment is represented by: a variable for relative energy prices (RELPR), the ratio of new investment to capital stock (RATIO), and capacity utilization (CU). The behavioral links between each of these explanatory variables and the OER is straightforward. As the relative price of energy increases, business will economize on its use; thus output per unit of energy will also increase. We also expect that as capacity increases, the ratio of output to energy will increase since the fixed energy consumption (e.g., in heating plants) is spread over more production, lowering the energy content of each unit of output. As investments are made that improve the energy efficiency of the capital stock, output per unit of energy should increase. But investment may not all be energy saving; labor saving or pollution abatement control investment may well be energy using, thus increasing the energy content of output. So the relationship between the RATIO variable and OER is ambiguous. But a positive relationship between the other environmental variables, RELPR and CU, and the output-energy ratio is expected.

Economic reasoning and statistical training suggest that we add a caveat at this point. We expect that the interrelationship between explanatory variables is strong. Relative energy price increases stimulate new investment to conserve energy use, suggesting a positive correlation between RELPR and RATIO. Investment is rarely undertaken when business conditions suggest that the new equipment will not be fully used -- a positive correlation between RATIO and CU. With movements of all these variables correlated, we can anticipate some statistical difficulty discriminating among influences. We might circumvent this problem by introducing another measure of technological change, for example, a time trend. We label these explanatory variables TIME and TSQ: the first is introduced to capture any linear influence that technological advance may have, the latter in the event that nonlinear effects may be significant. But we caution that problems may still remain. Among

those that can be anticipated are problems because of the intercorrelation of explanatory variables and problems because there may be lags in effects of changes in explanatory variables that take longer than a year to resolve. Having pointed out this problem, we now turn to the regression results.

Table 3.1 summarizes the major results of our regression analysis. Columns (1)-(5) show the results using the energy weighted OER for manufacturing and mining (OEEMM). For example, column (1) reports the regression using a constant term, RELPR, CU and RATIO. This formulation explains about 70 percent of the total variation in the OEEMM, with all explanatory variables except RATIO significant at the 5 percent level (t-values are in parenthesis under the estimated coefficients). Overall, the regression is encouraging, but a number of unsatisfactory aspects are evident. The sign of the RATIO term suggests one of two things: either investments have been energy using or, more likely, it is a reflection of the fact that all three of the explanatory variables move coincidentally. A more disturbing aspect of this regression is that the Durbin-Watson (D-W) statistic is very low -- an indication of positive serial correlation in the residuals. A statistical correction for this problem, devised by Cochrane and Orcutt (explained in any introductory econometric textbook), is used in the regression reported in column (2). Although decidedly better (higher corrected R-squared, improved D-W statistic), we must ask if there is an alternative specification of the equation that will alleviate the low D-W statistic without appealing to this correction procedure. Columns (3) and (5) explore this option by including TIME and TSQ as explanatory variables in the estimated equation.

Column (3) reports the regression that introduces a linear trend in time. It shows a significant improvement compared to the regressions shown in columns (1) and (2). The significance of CU improves dramatically, RATIO now enters with a positive sign, and all variables are significant at the 1 percent confidence level. The percentage of explained variation improves to over 98 percent of the total, which indicates a "tight" fit. And the D-W statistic is now close enough to its expected value that we can reject the possibility of positive serial correlation of the residuals; a result achieved without appealing to the correction procedure of Cochrane and Orcutt. This regression

TABLE 3.1. Regression Results Using Output/Energy Ratios

Explanatory Variables	Dependent Variables															
	OEEMM ^(a)					OEVM ^(a)					OEEL ^(a)			OEVI ^(a)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Constant	54.8 (1.4) ^(b)	54.0 (2.2)	30.1 (3.4)	24.5 (2.5)	18.6 (2.2)	59.3 (1.5)	96.8 (2.7)	34.9 (2.7)	26.0 (1.3)	29.9 (1.7)	96.6 (3.0)	75.8 (5.0)	56.8 (2.2)	88.4 (2.9)	71.8 (4.1)	57.8 (2.8)
RELPR	21.6 (6.4)	6.5 (2.5)	9.4 (9.6)	9.1 (8.9)	3.6 (1.6)	28.0 (7.9)	11.0 (2.9)	15.9 (9.1)	13.8 (6.6)	13.4 (2.9)	14.1 (5.0)	4.9 (2.9)	0.4 (0.1)	15.9 (5.9)	7.7 (3.9)	6.2 (2.9)
CU	.56 (2.7)	.49 (8.6)	.47 (10.0)	.48 (10.2)	.48 (11.9)	.64 (3.0)	.47 (5.6)	.56 (6.7)	.55 (6.7)	.56 (6.6)	.37 (2.2)	.30 (3.7)	.35 (4.3)	.46 (2.9)	.40 (4.3)	.42 (4.6)
RATIO	-13.9 (.9)	8.8 (.8)	11.6 (3.0)	14.2 (3.3)	20.3 (4.6)	-25.6 (1.6)	-16.9 (1.0)	-.35 (0.1)	6.32 (0.6)	3.4 (0.4)	-22.6 (1.7)	-3.2 (0.5)	7.5 (0.6)	-26.0 (2.1)	-8.8 (1.2)	-1.2 (0.1)
TIME			.74 (20.3)	.77 (17.7)	.92 (13.2)			.73 (11.3)	.87 (8.2)	.81 (5.5)		.56 (9.0)	.79 (4.7)		.50 (6.9)	.61 (6.4)
TSO					.026 (2.9)					.011 (.6)						
RHO		.96 (18.2)		.06 (.3)			.96 (18.5)		.36 (1.9)				.57 (3.6)			.19 (1.0)
Summary Regression Statistics																
R ² ^(c)	.70	.97	.98	.98	.99	.79	.96	.97	.98	.97	.64	.92	.93	.72	.91	.92
D-W ^(d)	0.3	2.2	1.8	1.9	2.0	0.4	1.5	1.3	1.3	1.2	0.5	1.4	2.2	.7	1.6	1.7
SEE ^(e)	4.2	1.3	.98	.95	.84	4.4	1.9	1.7	1.5	1.8	3.6	1.7	1.6	3.4	1.9	1.8

(a) See text for definition of variables.

(b) Numbers in parenthesis are t-values.

(c) R²: Coefficient of determination adjusted for degrees of freedom.

(d) D-W: Durbin-Watson Statistic.

(e) SEE: Standard Error of the Estimate.

has been repeated on Table 3.2. Beneath the regression output is a plot of the actual and fitted values over the sample period, with a residual plot on the right side. The regression errors are outside a narrow (.98) SEE band on six occasions: in 1954, 1957, 1959, and 1978-1980.

The responsiveness of the OER to the explanatory variables can be calculated using the average values of the variables and the estimated coefficients. These calculated response coefficients, called elasticities, indicate the percentage change of the OER for a fixed percentage change in one of the explanatory variables. Using the equation shown in Table 3.2, for example, a 10 percent increase in the explanatory variables would increase the OER by 1 percent for RELPR, 4 percent for CU, and 2 percent for RATIO. The coefficient for TIME suggests that the OER will improve at the rate of about 0.7 percent per year as a result of technological improvements and other trend factors.

Columns (4) and (5) of Table 3.1 show two further regressions using OEEMM as the dependent variable. Column (4) applies the Cochrane-Orcutt correction to the regression of Column (3), and, as we would expect, shows little improvement. The first order serial correlation coefficient, RHO , is insignificant, and the coefficients are little changed in either magnitude or significance. Column (5) adds a quadratic in time, TSQ , to the regression of Column (3), to check for the significance of nonlinearities in technological change. On balance, this specification is not an improvement. The coefficient on RELPR is much smaller and loses its significance. This most likely occurs because of the sharp increase in relative energy prices since 1973, coupled with a declining trend in energy prices in the early part of the sample period. The quadratic in time, which exaggerates this pattern, now enters significantly as an explanatory variable and removes the significance of the relative price term. On the basis of statistical parsimony, we reject both of these specifications.

Columns (6)-(10) of Table 3.1 repeat these five regressions using the value-added weighted OER (OEVMM) as the dependent variable. In some respects, the results are similar. Without a time trend, the results are unsatisfactory and are only modestly improved after correcting for serial correlation in the

TABLE 3.2. Regression Results for OEEMM

ORDINARY LEAST SQUARES

VARIABLES...

	OEEMM	#C	RELPR	CU	RATIO	TIME
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC	CONTRIBUTION TO R ²	
#C	1	30.1033	8.81130	3.41644		
RELPR	1	9.43131	.978320	9.64031	.566913D-01	
CU	1	.469848	.467963D-01	10.0403	.614930D-01	
RATIO	1	11.5515	3.81832	3.02528	.558297D-02	
TIME	1	.737618	.362778D-01	20.3325	.252183	

R-SQUARED = 0.9866

R-SQUARED(CORRECTED) = 0.9841

MULTICOLLINEARITY EFFECT= 0.6106

DURBIN-WATSON STATISTIC= 1.8431

F(4,22)= 404.3314

NUMBER OF OBSERVATIONS = 27

SUM OF SQUARED RESIDUALS= 20.9393

STANDARD ERROR OF THE REGRESSION = .975595

ACTUAL VALUES PLOTTED WITH (+)

FITTED VALUES PLOTTED WITH (x)

RESIDUALS PLOTTED WITH (0)

0 LINES AT + AND - .9756

ACTUAL VALUES FITTED VALUES

RESIDUALS

1	89.7585	88.6329	x+	1.12562	.	0	.
2	92.6575	92.6977	x	-.401903D-01	.	0	.
3	92.3362	92.8915	+x	-.555257	.	0	.
4	91.5944	92.8005	+x	-1.20611	0	.	.
5	89.7228	89.5457	x	.177058	.	0	.
6	95.4872	93.6160	x +	1.87120	.	.	0
7	93.7385	93.9672	x	-.228676	.	0	.
8	94.1806	93.8233	x	.357289	.	0	.
9	96.4676	96.5296	x	-.620291D-01	.	0	.
10	97.6440	98.1985	+x	-.554434	.	0	.
11	98.8135	99.3943	+x	-.580809	.	0	.
12	101.790	101.450	x	.339795	.	0	.
13	102.089	102.333	x	-.244106	.	0	.
14	100.000	100.745	+x	-.744641	0	.	.
15	100.566	101.166	x	-.599636	.	0	.
16	102.123	101.352	x+	.771032	.	.	0.
17	98.5900	99.0232	x	-.433212	.	0	.
18	99.7573	99.8265	+x	-.692332D-01	.	0	.
19	103.463	102.949	x+	.513472	.	0	.
20	105.527	106.259	+x	-.732466	0	.	.
21	107.715	107.905	x	-.189675	.	0	.
22	103.733	104.317	+x	-.584278	.	0	.
23	108.323	108.447	x	-.123637	.	0	.
24	110.423	111.053	+x	-.629373	.	0	.
25	115.104	112.565	x +	2.53902	.	.	0
26	116.976	115.687	x +	1.28848	.	.	0
27	115.645	117.250	+ x	-1.40521	0	.	.

residuals. Adding a quadratic in time does not significantly improve the regression fit, although in this case the relative price term is not so adversely affected. But there are also some noticeable differences from those reported earlier. The coefficients on both capacity and relative price are uniformly higher. These higher coefficients and a lower average value for OEVM raise the responsiveness of the OER to changes in RELPR and CU. Based on the regression reported in Column (8) -- and shown in more detail in Table 3.3 -- a 10 percent increase in the explanatory variables would increase OEVM by 2 percent for RELPR and 5 percent for CU. These are somewhat higher than in the energy weighted OER regressions. It is also worth noting that the ratio of new investment to capital stock is not a significant explanatory variable in these regressions. These differences suggest that the question of the energy intensity of the industrial sector be examined in an alternative way, which we do in Section 4.0. But before turning to this question, we look briefly at broader measures of the OER for the industrial sector.

Columns (11)-(13) and (14)-(16) show regressions of our explanatory variables and time on broader measures of the OER for the entire industrial sector--including agriculture (OEEI and OEVI). Using the energy weighted OER for the entire industrial sector, OEEI, the major difference appears to be the lack of improvement in the D-W statistic when time is introduced. When the Cochrane-Orcutt correction is made, the relative price term loses significance. For OEVI, the value-added weighted OER, the major difference is that the sign of RATIO is uniformly negative, although insignificant in Columns (15) and (16). These equations suggest that the estimated results discussed previously are fairly robust with respect to this set of data.

TABLE 3.3. Regression Results for OEVM

ORDINARY LEAST SQUARES

VARIABLES...

	OEVM	#C	RELPR	CU	RATIO	TIME
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC	CONTRIBUTION TO R ²	
#C	1	34.8873	15.7281	2.21814		
RELPR	1	15.9116	1.74630	9.11161	.101838	
CU	1	.556396	.835313D-01	6.66092	.544235D-01	
RATIO	1	-.345912	6.81570	-.507523D-01	.315958D-05	
TIME	1	.730987	.647558D-01	11.2883	.156307	
R-SQUARED = 0.9730						
R-SQUARED(CORRECTED) = 0.9681						
MULTICOLLINEARITY EFFECT= 0.6604						
DURBIN-WATSON STATISTIC= 1.2885						
F(4,22)= 198.3084						
NUMBER OF OBSERVATIONS = 27						
SUM OF SQUARED RESIDUALS= 66.7171						
STANDARD ERROR OF THE REGRESSION = 1.74143						

ACTUAL VALUES PLOTTED WITH (+)
FITTED VALUES PLOTTED WITH (x)

RESIDUALS PLOTTED WITH (0)
LINES AT + AND - 1.741

ACTUAL VALUES	FITTED VALUES		RESIDUALS
1	89.1363	86.4332	x + 2.70304
2	88.5272	90.6818	+ x -2.15467
3	88.2176	90.6051	+ x -2.38744
4	88.6655	90.3787	+ x -1.70521
5	86.7368	85.6027	x+ 1.13411
6	92.1060	89.7048	x + 2.40115
7	89.9629	89.7276	x .235333
8	89.5104	89.1617	x .348731
9	92.8485	92.0872	x+ .761237
10	93.4763	93.9374	x -.461073
11	93.4359	95.3809	+ x -1.94504
12	98.2391	98.3441	x -.105022
13	100.762	100.020	x+ .742293
14	100.000	98.5394	x + 1.46061
15	100.566	98.7681	x + 1.79791
16	100.207	98.8489	x+ 1.35766
17	94.3890	95.8982	+x -1.50915
18	95.8172	96.6582	+x -.840998
19	100.291	100.167	x .124067
20	103.328	104.315	+x -.987124
21	105.210	107.795	+ x -2.58487
22	103.099	103.820	x -.720531
23	107.224	108.651	+ x -1.42742
24	111.332	112.084	+x -.752084
25	116.734	113.676	x + 3.05828
26	120.018	118.137	x + 1.88082
27	120.949	121.454	+x -.504607

4.0 ANNUAL MEASURES OF ENERGY INTENSITY

A number of energy intensity measures can be conceived, based on the value-added and energy weighted measures of output used before. The difference between the two output-energy ratios would be one such measure. But these differences provide no relative reference--is this period's change large or small relative to the current level? Percentage changes and ratios of OERs provide an alternative measure of the relative changes in energy intensiveness of the industrial sector. We begin by analyzing the differences between the energy weighted OER and the value-added weighted OER; we title this variable DIFF. Since total energy is the same in both cases, subtracting the two yields a measure of the difference in output per unit of energy use that can be attributed directly to differences in weights applied to the output index. In subsection 4.1, this measure of energy intensity is investigated. In 4.2, alternative specifications, namely percentage changes and ratios, are examined. There appears to be little substantive difference in the conclusions that one draws from these alternative measures. In 4.3, changes in energy intensity that actually occurred are compared with those that might have been reasonably expected if the explanatory variables had continued to follow trend values. This final section allows the decomposition of the total shift into components attributable to changes in energy price, to changes in other factors, and to a residual.

4.1 DIFFERENCE IN ENERGY INTENSITY

Before examining the regression results, it is worth reviewing the ways that changes in the explanatory variables might influence each of the output-energy ratios, and thus, the differences in these ratios (DIFF). An increase in the relative price of energy would lead to economizing in the use of energy, thus increasing output per unit of energy, no matter how the output measure was weighted. However, since rising relative energy prices would cause the price of energy-intensive output to increase proportionately more than other output, consumers would shift away from these outputs or other industries would use less of them as intermediate goods. Thus, the energy weighted output measure would increase less than would the value-added measure. Hence the difference,

TABLE 4.1. Ordinary Least Squares Regression Results
for DIFF--Three Explanatory Variables

EXECUTION STARTED
ORDINARY LEAST SQUARES

VARIABLES...

DIFF #C RELPR CU RATIO

INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC	CONTRIBUTION TO R ²
#C	1	-4.56210	11.3802	-.400880	
RELPR	1	-6.37089	1.00910	-6.31344	.390888
CU	1	-.8576130-01	.6076320-01	-1.41140	.1953540-01
RATIO	1	11.6679	4.70228	2.48133	.6037950-01

R-SQUARED = 0.7744

R-SQUARED(CORRECTED) = 0.7450

MULTICOLLINEARITY EFFECT= 0.3036

DURBIN-WATSON STATISTIC= 1.1926

F(3,23)= 26.3240

NUMBER OF OBSERVATIONS = 27

SUM OF SQUARED RESIDUALS= 37.2231

STANDARD ERROR OF THE REGRESSION = 1.27216

ACTUAL VALUES PLOTTED WITH (+)
FITTED VALUES PLOTTED WITH (x)

RESIDUALS PLOTTED WITH (0)
LINES AT + AND - 1.272

ACTUAL VALUES FITTED VALUES

RESIDUALS

	ACTUAL VALUES	FITTED VALUES		RESIDUALS
1	.622243	2.28400	+	-1.66176
2	4.13035	2.16998	x	1.96036
3	4.11859	2.35138	x	1.76722
4	2.92889	2.48727	x	.441617
5	2.98602	3.97314	+	-.987118
6	3.38128	3.92987	+	-.548593
7	3.77558	4.24658	+	-.471003
8	4.67011	4.65611	x	.1399870-01
9	3.61909	4.43111	+	-.812013
10	4.16773	4.24503	x	-.7729610-01
11	5.37760	3.99415	x	1.38346
12	3.55081	3.09431	x	.456499
13	1.32716	2.30921	+	-.982050
14	.0	2.20008	+	-2.20008
15	.0	2.38262	+	-2.38262
16	1.91652	2.48060	+	-.564078
17	4.20103	3.09001	x	1.11102
18	3.94015	3.12633	x	.813817
19	3.17160	2.73665	x	.434956
20	2.19847	1.90310	x	.295373
21	2.50500	.9638560-01	x	2.40861
22	.633620	.478167	x	.155453
23	1.09930	-.222900	x	1.32220
24	-.908495	-1.04357	x	.135070
25	-1.63036	-1.12987	+	-.500492
26	-3.04249	-2.45372	+	-.588768
27	-5.10441	-4.18063	+	-.923777

as it is defined here, would decrease. In other words, the sign of the relative price variable should be negative in the regression equation.

The independent influence of the capacity variable should also be negative. As capacity declines, output per unit of energy should also decline, since space heating and other such fixed energy used are spread over a smaller output. But these capacity inefficiencies are likely to be more important in the less energy-intensive industries since the output of energy-intensive industries is more closely correlated with energy use. In other words, the "fixed" energy requirements of a less energy-intensive industry are a greater proportion of the total energy use than is the case in a more energy intensive industry. Thus, when the OER declines as capacity is lowered, it will decline relatively less for energy-weighted output, hence increasing DIFF.

The influence of changes in the ratio of new investment to capital stock is ambiguous--it depends on the type of new investment that is purchased. If the new investment is energy saving, then this new investment will increase the efficiency of energy use and retard the shift from more to less energy-intensive output. In this case, the sign of the ratio variable would be positive. But if this new investment is labor saving or abates pollution (in the latter part of this period, much of new investment resulted from legislation requiring that pollution abatement measures be undertaken) then the sign of the ratio variable could be negative. The ambiguity associated with new investment relative to capital stock is not resolved by this knowledge. Although intuition suggests that pollution abatement investments might be energy using, this is not always the case. Improvements in efficiencies of automotive power plants and coil coating processes are two examples to the contrary. Pollution abatement requirements in both of these cases led to process efficiencies that have generally been energy saving.

The results of our initial regression, reported in Table 4.1, bear out our expectations based on economic reasoning. The relative price term (RELPR) enters with the expected negative sign and is highly significant. The capacity variable (CU) also enters with the correct sign, but is not statistically significant at the 5 percent level (although it is at the 10 percent level). The investment ratio (RATIO) is also significant and enters with a positive

sign, suggesting that some new investment might have been stimulated by increased energy costs. And on the whole, the regression works quite well. The independent variables explain about three-quarters of the total variation in the difference, with only one observation in the period since 1972 outside one standard error--1974: a year of supply shortages, relaxation of price controls and the beginning of a recession. But there is one unsatisfactory aspect of this regression: the Durbin-Watson statistic is low (1.19), suggesting positive serial correlation of the residuals. Since this might be caused by either the lack of a significant variable or serial correlation, alternative specifications are tried.

Table 4.2 reports two further regressions. The first drops the *RATIO* variable and introduces in its stead *TIME*, a time trend explained in Section 3. On balance, this contributes negatively--the explained variation declines and now two of the variables are insignificant. Moreover, the signs of both *RELPR* and *CU* are now reversed. The second regression in Table 4.2 adds *RATIO* again, simply altering Table 4.1 by the addition of *TIME*. But again, there is no net improvement in specification. *TIME* is not significant, nor is the D-W statistic improved. The explanatory power of the equation, adjusted for degrees of freedom, declines. As with the first regression on this table, the signs of all the other explanatory variables are reversed from those of Table 4.1. Clearly these specifications are less than satisfactory alternatives relative to the first equation.

Much the same thing can be said for the regression reported on Table 4.3. In this case, we try to correct the low D-W statistic by invoking the Cochrane-Orcutt procedure to correct for serial correlation of residuals. The correction parameter (*RHO*) suggests that there is significant autocorrelation from year to year; *RHO* is significant at the 5 percent level. But on closer examination, there is little improvement. The significance of *CU* declines further, but more important, the D-W still indicates positive serial correlation of residuals. These results are contrary to the findings of Section 3, in that there does not appear to be any obvious method that can be invoked to correct for the problems of serial correlation. This suggests that one or more explanatory variables that should logically be included are missing

TABLE 4.3. Further DIFF Regression Results--
Correction for Serial Correlation

COCHRANE-ORCUTT ITERATIVE PROCEDURE

VARIABLES...

DIFF	#C	RELPR	CU	RATIO
MEAN OF DEPENDENT VARIABLE IS			2.03897	
ITERATION		RHO		
XXXXXXXX		XXX		

1 0.4289546

2 0.4505271

3 0.4578374

4 0.4603434

FINAL VALUE OF RHO=	0.4603434
NO. OF ITERATIONS=	4

STANDARD ERROR OF RHO=	0.1741003
T-STATISTIC FOR RHO=	2.6441269

INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
#C	1	-12.8377	15.4226	-0.832395
RELPR	1	-6.25606	1.34037	-4.66741
CU	1	-0.2902350-01	0.6049290-01	-0.479782
RATIO	1	13.6117	7.02830	1.93670

R-SQUARED = 0.824130

R-SQUARED(CORRECTED) = 0.800148

DURBIN-WATSON STATISTIC= 1.3446

NUMBER OF OBSERVATIONS = 26

SUM OF SQUARED RESIDUALS= 28.6841

STANDARD ERROR OF THE REGRESSION = 1.14185

R-SQUARED IN TERMS OF CHANGES = 0.4441

TABLE 4.2. Ordinary Least Squares Regression Results for DIFF--
Three Explanatory Variables and TIME

ORDINARY LEAST SQUARES

VARIABLES...

	DIFF	#C	RELPR	CU	TIME	
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R**2	
#C	1	-19.2608	6.19409	-3.10954		
RELPR	1	6.95278	1.40759	4.93950	.298462	
CU	1	.110798	.672040D-01	1.64868	.332501D-01	
TIME	1	.305296D-01	.498975D-01	.611846	.457938D-02	
R-SQUARED = 0.7186						
R-SQUARED(CORRECTED) = 0.6819						
MULTICOLLINEARITY EFFECT= 0.3824						
DURBIN-WATSON STATISTIC= 1.1310						
F(3,23)= 19.5827						
NUMBER OF OBSERVATIONS = 27						
SUM OF SQUARED RESIDUALS= 46.4318						
STANDARD ERROR OF THE REGRESSION = 1.42084						

ORDINARY LEAST SQUARES

VARIABLES...

	DIFF	#C	RELPR	CU	RATIO	TIME	
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R**2		
#C	1	4.78401	11.7430	.407392			
RELPR	1	6.48030	1.30383	4.97021	.253048		
CU	1	.865479D-01	.623665D-01	1.38773	.197271D-01		
RATIO	1	-11.8974	5.08876	-2.33797	.559928D-01		
TIME	1	-.663156D-02	.483483D-01	-.137162	.192718D-03		
R-SQUARED = 0.7746							
R-SQUARED(CORRECTED) = 0.7337							
MULTICOLLINEARITY EFFECT= 0.4457							
DURBIN-WATSON STATISTIC= 1.1942							
F(4,22)= 18.9055							
NUMBER OF OBSERVATIONS = 27							
SUM OF SQUARED RESIDUALS= 37.1913							
STANDARD ERROR OF THE REGRESSION = 1.30020							

from this regression specification. Rather than speculate on what these might be, at this juncture we simply select the best available specification and continue the analysis of alternative measures.

Table 4.4 is a plot, on a slightly enlarged scale, of the actual and fitted dependent variable from the regression reported in Table 4.1. The error from this equation is decomposed in the statistics reported below the graph. These statistics indicate that the RELPR, CU, and RATIO serve quite well in explaining the variation that occurs in the difference variable. The Theil inequality coefficient is less than 0.2, indicating that this equation forecasts better than a naive forecasting model based on previous values of the difference. A decomposition of the error indicates that the bulk of the unexplained error is attributable to differences in covariation, for which there is no statistical correction. There appears to be no discernable bias in the equation, although differences in variance of the two series can account for slightly more than 6 percent of the error. There are two time periods that seem to account for this difference in variance--1954-56 shows quite a wide dispersion of energy and value-added weighted output-energy ratios that is not explained by the independent variables; and 1967-68, because of the normalization procedure, drops to zero. In the post-embargo period, only one year, 1974, shows a large discrepancy from the data, a point mentioned before.

4.2 ALTERNATIVE SPECIFICATIONS

A number of alternative measures to the difference between energy weighted and value-added weighted OERs were examined. Among these were percentage differences--the difference relative to the value of either of the OERs--and ratios. These ratios were constructed by dividing one OER by the other; this is comparable to the ratio of, say, energy weighted output to value-added weighted output, since both measures of total energy use are the same.

Table 4.5 is an example of the results obtained, using the ratio of the energy weighted to the value-added weighted output series as the dependent variable. Since both the output indexes are equal to 100 in 1967, the normalization that applies is $1967 = 1.0$. In most years, energy weighted output was larger than

TABLE 4.4. PLOT and Decomposition of Regression
Results Shown in Table 4.1

DIFF IS REPRESENTED BY *
FITTED IS REPRESENTED BY X

CORRELATION COEFFICIENT = .98003
 SQUARED = .77445
 ROOT-MEAN-SQUARED ERROR = 1.1742
 MEAN ABSOLUTE ERROR = .94071
 MEAN ERROR = 2.2204E-15
 REGRESSION COEFFICIENT OF ACTUAL ON PREDICTED = 1
 THEILS INEQUALITY COEFFICIENT = .19193
 FRACTION OF ERROR DUE TO BIAS = 3.5763E-30
 FRACTION OF ERROR DUE TO DIFFERENT VARIATION = .063814
 FRACTION OF ERROR DUE TO DIFFERENT COVARIATION = .93619
 ALTERNATIVE DECOMPOSITION (LAST 2 COMPONENTS):
 FRACTION OF ERROR DUE TO DIFFERENCE OF REGRESSION
 COEFFICIENT FROM UNITY = 1.2875E-30
 ERROR DUE TO RESIDUAL VARIANCE = 1

TABLE 4.5. Regression of RATIOEV Against Three Explanatory Variables

ORDINARY LEAST SQUARES

VARIABLES...

	RATIOEV	#C	RELPR	CU	RATIO
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC	CONTRIBUTION TO R ²
#C	1	.913392	.116499	7.84033	
RELPR	1	-.591961D-01	.103301D-01	-5.73044	.337814
CU	1	-.901992D-03	.622030D-03	-1.45008	.216314D-01
RATIO	1	.139760	.481371D-01	2.90338	.867180D-01

R-SQUARED = 0.7634

R-SQUARED(CORRECTED) = 0.7325

MULTICOLLINEARITY EFFECT= 0.3172

DURBIN-WATSON STATISTIC= 1.2585

F(3,23)= 24.7357

NUMBER OF OBSERVATIONS = 27

SUM OF SQUARED RESIDUALS= .390081D-02

STANDARD ERROR OF THE REGRESSION = .130231D-01

ACTUAL VALUES PLOTTED WITH (+)
FITTED VALUES PLOTTED WITH (x)

RESIDUALS PLOTTED WITH (0)
LINES AT + AND - .1302D-01

ACTUAL VALUES	FITTED VALUES	RESIDUALS									
1	1.00698	1.02381	+	x	-.168324D-01	0	.	.			
2	1.04666	1.02289		x	+	.237661D-01	.	.	0		
3	1.04669	1.02471		x	+	.219803D-01	.	.	0		
4	1.03303	1.02648		x	+	.655117D-02	.	0	.		
5	1.03443	1.04245			+	x	-.802309D-02	.	0	.	
6	1.03671	1.04245			+	x	-.573624D-02	.	0	.	
7	1.04197	1.04620			+	x	-.422820D-02	.	0	.	
8	1.05217	1.05104				x	.113328D-02	.	0	.	
9	1.03898	1.04877			+	x	-.979034D-02	.	0	.	
10	1.04459	1.04675			+	x	-.216319D-02	.	0	.	
11	1.05755	1.04346				x	+	.140931D-01	.	.	0
12	1.03614	1.03327			x	+	.287619D-02	.	0	.	
13	1.01317	1.02410		+	x		-.109317D-01	.	0	.	
14	1.00800	1.02239		+	x		-.223912D-01	0	.	.	
15	1.00800	1.02399		+	x		-.239891D-01	0	.	.	
16	1.01913	1.02484			+	x	-.571446D-02	.	0	.	
17	1.04451	1.03150				x	+	.130125D-01	.	.	0
18	1.04112	1.03254				x	+	.858542D-02	.	.	0
19	1.03162	1.02844				x	+	.318005D-02	.	0	.
20	1.02128	1.02005				x	+	.122552D-02	.	0	.
21	1.02381	1.00292			x	+	.208899D-01	.	.	.	0
22	1.00615	1.00744			+	x	-.129923D-02	.	0	.	
23	1.01025	1.00034			x	+	.991623D-02	.	.	.	0
24	.991840	.992370			+	x	-.530383D-03	.	0	.	
25	.986034	.991411			+	x	-.537714D-02	.	0	.	
26	.974650	.978903			+	x	-.425334D-02	.	0	.	
27	.957797	.963747			+	x	-.594983D-02	.	0	.	

value-added output, so the ratio exceeds one. Since 1970, this ratio has declined, falling below 1.0 in 1977 for the first time.

The equation reported in Tables 4.5 and 4.6 is only modestly different from the equation reported in Section 4.1. The relative price term is highly significant, as is the ratio of new investment to capital stock. As before, capacity utilization enters with the expected sign, but is not significant at the 5 percent level of confidence. About the same proportion of total variation is explained by the equation and the low D-W statistic remains a problem. The residual plot in Table 4.5 indicates that 1974 is again the only year after the sharp increase in oil prices for which the estimating equation leaves a residual outside the single standard error bounds. Table 4.6 shows the actual and fitted values of the dependent variable on a somewhat larger scale and decomposes the residual error. This decomposition indicates that this version of the difference equation may be somewhat better than the version reported in section 4.2. In this case, the Theil inequality coefficient is nearly zero, indicating considerable improvement over the naive forecast based on past values. Again, there remains about 7 percent of the error attributable to differences in variance, much of which can be explained by the early years of the sample, 1967-68 and 1974.

Table 4.7 reports two other versions of the difference equation to illustrate that there appears to be little difference between specifications of this equation. The first of these regresses PCTDIF against our cadre of explanatory variables. PCTDIF is constructed by dividing the difference used in section 4.1 by the energy weighted OER. The second regression reported uses the same measure, but normalized to the value-added weighted OER rather than the energy weighted OER. Again, the variables enter the correct signs, RELPR is most significant, and the problem with the D-W statistic remains. For other regressions that were tried but are not reported, the results were similar.

As a result of trying a variety of different specifications, a number of generalizations seem in order. About three-quarters of the variation in the shift from more to less energy-intensive industrial production can be explained by a limited set of economic variables--relative energy prices, capacity utilization and the ratio of new investment to capital stock. With the

TABLE 4.6. PLOT and Decomposition of Regression
Shown in Table 4.5

RATIOEV IS REPRESENTED BY x
FITTED IS REPRESENTED BY X

CORRELATION COEFFICIENT = .87372
 SQUARED = .76339
 ROOT-MEAN-SQUARED ERROR = .01202
 MEAN ABSOLUTE ERROR = .009423
 MEAN ERROR = 8.8818E-16
 REGRESSION COEFFICIENT OF ACTUAL ON PREDICTED = 1
 THEIL'S INEQUALITY COEFFICIENT = .0058783
 FRACTION OF ERROR DUE TO BIAS = 5.4602E-27
 FRACTION OF ERROR DUE TO DIFFERENT VARIATION = .067394
 FRACTION OF ERROR DUE TO DIFFERENT COVARIATION = .93261
 ALTERNATIVE DECOMPOSITION (LAST 2 COMPONENTS):
 FRACTION OF ERROR DUE TO DIFFERENCE OF REGRESSION
 COEFFICIENT FROM UNITY = 2.0829E-32
 ERROR DUE TO RESIDUAL VARIANCE = 1

TABLE 4.7. Regressions of Percentage Differences
Against Three Explanatory Variables

ORDINARY LEAST SQUARES

VARIABLES...

	PCTDIF	#C	RELPR	CU	RATIO	
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R**2	
#C	1	-.701551D-01	.112245	-.625018		
RELPR	1	-.594410D-01	.995289D-02	-5.97223	.356242	
CU	1	-.890234D-03	.599316D-03	-1.48542	.220378D-01	
RATIO	1	.129678	.463793D-01	2.79602	.780825D-01	
R-SQUARED = 0.7703						
R-SQUARED(CORRECTED) = 0.7403						
MULTICOLLINEARITY EFFECT= 0.3139						
DURBIN-WATSON STATISTIC= 1.2386						
F(3,23)= 25.7072						
NUMBER OF OBSERVATIONS = 27						
SUM OF SQUARED RESIDUALS= .362113D-02						
STANDARD ERROR OF THE REGRESSION = .125475D-01						

ORDINARY LEAST SQUARES

VARIABLES...

	PCTDIFV	#C	RELPR	CU	RATIO	
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R**2	
#C	1	-.866085D-01	.116499	-.743426		
RELPR	1	-.591961D-01	.103301D-01	-5.73044	.337814	
CU	1	-.901992D-03	.622030D-03	-1.45008	.216314D-01	
RATIO	1	.139760	.481371D-01	2.90338	.867180D-01	
R-SQUARED = 0.7634						
R-SQUARED(CORRECTED) = 0.7325						
MULTICOLLINEARITY EFFECT= 0.3172						
DURBIN-WATSON STATISTIC= 1.2585						
F(3,23)= 24.7357						
NUMBER OF OBSERVATIONS = 27						
SUM OF SQUARED RESIDUALS= .390081D-02						
STANDARD ERROR OF THE REGRESSION = .130231D-01

FIGURE 4.1. Actual and Trend Values for Explanatory Variables

exception of 1974--a perverse year at best--these explanatory variables account for much of the shift since the sharp run-up in energy prices began in the early 1970s. Among these explanatory variables, the ratio of energy to output prices is clearly the most significant factor. The other two economic variables enter the regressions with the correct sign but are not as useful an explanatory variable as is relative price. But there remain a number of disturbing indicators that suggest some of causal variables have been ignored--most prominently, no statistical correction will redeem a low Durbin-Watson statistic, which suggests that some major explanatory factor has been left out.

In the final section of this paper, we will return to the problem presented by these regression results. But for now, we will carry these results one step further, by decomposing the shifts that have occurred into explained and unexplained portions.

4.3 DECOMPOSITION OF EFFECTS

To determine the effects that might have occurred without the major shifts that began in the early 1970s, we need to establish a base case. To this purpose we make some assumptions about the trend value of the explanatory variables, then forecast DIFF or RATIOEV based on these trends. To establish trends for RELPR, CU and RATIO, these explanatory variables were regressed against time over the period 1954 to 1972. Of the regressions, only RELPR displayed any time trend--a slight decline of about one-half of one percent per year. For CU and RATIO, since no time trend was evidenced by the data, a simple average over the period 1954-1972 was used. The actual and trend values for these explanatory variables is plotted in Figure 4.1. Trend values (or averages) are shown for the period beginning in 1973, as well as the actual values reported in the appendix and used in the regressions. Notice that the actual value of RATIO is lower during the forecast period than the average for the entire sample period; that CU fluctuates about its sample period average during forecast period; and that RELPR increases every year, except 1978, during the forecast period, whereas a trend value would have seen relative energy prices decline over the forecast period.

Substituting these base case values into the DIFF equation reported in Section 4.1 provides a base forecast of the difference that might have occurred had the explanatory variables followed trend values. This prediction based on trend is labeled "TREND" and is shown on Figure 4.2. The actual value, labeled "ACTUAL," is the solid line that ends with a triangle. The curve labeled "FORECAST" is a plot of the fitted values from the equation, as shown in Table 4.1. The remaining curve shown on this chart, labeled "ACTUAL RELPR ONLY," gives an indication of the influence of the change in relative energy prices, holding the other explanatory variables at their trend values. The symbols on the right-hand margin of this chart indicate the relative influence of the explanatory variables for the last year in the sample, 1980. Changes in the relative price of energy, represented by the distance from the empty box to the box with the X in it, accounts for about 84 percent of the total change (from the triangle to the upper box). The addition of the other factors, represented by the line ending with an X, (CU, RATIO) accounts for about 5 percent, leaving about 11 percent unaccounted for--the distance from the triangle to the X.

Figure 4.3 repeats this exercise using the RATIOEV equation rather than the difference equation. There is little substantive difference, although the numbers have changed somewhat. Now changes in relative price alone account for about 85 percent of the total variation, other factors for about 7 percent, leaving about 8 percent unexplained. Figures 4.2 and 4.3 provide convincing evidence that shifts in relative energy prices, of the independent variables used in this analysis, provide the bulk of the explanation of changes in the energy intensity within the industrial sector, accounting for 84 and 85 percent of the total change in 1980.

But is this really an explanation of cause? Or even an adequate description of change? As a first approximation, changes in relative energy prices appear to account for a substantial portion of the change that has occurred in the energy-intensity measures we have used--the difference between our ratio of energy weighted and value-added weighted OERs. But it is clear that other factors are also important; the statistical evidence clearly indicates that some explanatory factors are missing. So even as a description of change, it is limited. And it is far from an explanation of cause; economic

FIGURE 4.2. Actual, Trend and Forecast for Difference in Output-Energy Ratios

FIGURE 4.3. Actual, Trend and Forecast for Ratio of Industrial Production Indexes

agents are responsible for and bring about changes in behavior. This analysis brings us no closer to answering which agents are responsible for what shifts that result in these changed measures of energy intensity than we were at the beginning. The limited conclusion that we can draw is this: dramatic shifts in relative energy prices stimulate changes in the behavior of economic agents that lead to a change in the energy productivity of the industrial sector. Whether the responsible agents are individuals altering their consumption behavior, or producers adjusting their factor inputs in response to changing prices, or some other phenomena, this analysis cannot say. In the concluding section, we will return to the question of causes. Now we turn to a monthly analysis of changes in industrial energy productivity.

5.0 MONTHLY MEASURES OF ENERGY INTENSITY

This section estimates the relative importance of economic and seasonal factors that influence energy productivity using monthly data. Of interest here are the influence of changing relative prices and cyclical measures of capacity both of which were used in previous sections. Monthly data allows us to examine another possible explanatory variable that affects energy productivity--seasonal factors. The impact of these variables is examined using regression analysis over the period 1973 to 1980. Our focus, again, is on two measures of energy productivity: output-energy ratios (OER) constructed with value-added weights and OER constructed using energy-consumption weights. The difference in these two ratios serves as an indicator of the shifts in energy intensity of industrial output.

The monthly data used in the analysis include total energy consumption, indexes of output constructed from Federal Reserve indexes, capacity utilization indexes published by the Federal Reserve Board, the ratio of energy prices to industrial output prices and seasonal factors. Seasonality of energy use is of special concern; it is handled with the use of an indicator of seasonal energy demand, heating degree days, and dummy variables that capture the annual cycle of energy consumption. Section 5.1 reports the results of a variety of regression specifications designed to discriminate between the relative importance of factors that influence monthly energy use. Section 5.2 summarizes the findings of this section and compares these results to those found in previous sections.

5.1 ANALYSIS OF MONTHLY DATA

We begin our analysis by postulating a behavioral relationship between the energy weighted output-energy ratio (OER) and several cyclical and seasonal variables. In the list of explanatory variables we include heating degree days (HDD): as HDD increases, we would expect a decline in the OER as more energy is consumed for space heating that makes little direct contribution to output. Relative prices (RELPR) and capacity utilization (CU) are included for the

same reasons as they were before. We expect the sign of HDD to be negative with the sign of the other two variables positive.

The results of the first two regressions, using a monthly version of OEEMM as the dependent variable and shown on Table 5.1, generally bear out our assumption about the direction of effects. The effect of weather, captured in HDD, enters with a negative sign and is statistically significant at the 1% level of confidence (t-value greater than 2.63). Relative price, as expected, enters with a positive sign and is significant at the 5 percent level (greater than 2.0). Capacity utilization also enters with the correct sign and is also significant at the 5 percent level of confidence. But the summary statistics indicate a rather poor fit between the actual and forecast values. The coefficient of determination adjusted for degrees of freedom is only .39, suggesting that the equation leaves more than 60 percent of the variation in the data unexplained. Moreover, the Durbin-Watson statistic is 1.1, suggesting strong positive serial correlation in the residuals.

With monthly data, it is quite likely that the effects of the HDD variable are inadequate to capture all the seasonal variation in output. To determine if this is the case, an array of dummy variables is constructed consisting of columns for each of the months. In the January vector, each observation occurring in January is defined as a 1, with all other observations set equal to zero. So in this particular data set, the first column of this dummy array has a 1 in positions 1, 13, 27, . . . and 85. The last column of this dummy array, corresponding to the month of December, has a 1 in locations 12, 24, . . . , and 96, with zeros in all other locations. We then introduce this array into the regression in place of the constant term. Using this array is equivalent to allowing a separate regression intercept for each of the 12 months. With an intercept of 75.8 for the first regression, we would expect the seasonal intercepts to be about the same magnitude, with some variation over the year. In the colder months which require greater use of energy for space heating, we would expect this intercept to be lower than in the spring and fall months. The second panel in Table 5.1 shows the output of this regression.

TABLE 5.1. Regression of Monthly OEEMM Against Three Explanatory Variables and Monthly Dummy Variables

ORDINARY LEAST SQUARES

VARIABLES...

OEEMM	#C	RELPR	CU	HDD		
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R ²	
#C	1	75.8151	14.8251	5.11398		
RELPR	1	6.54789	2.76914	2.36459	.373478D-01	
CU	1	.358538	.159384	2.24953	.338014D-01	
HDD	1	-.143295D-01	.209422D-02	-6.84237	.312727	
R-SQUARED = 0.3855						
R-SQUARED(CORRECTED) = 0.3654						
MULTICOLLINEARITY EFFECT= 0.0016						
DURBIN-WATSON STATISTIC= 1.1452						
F(3,92)= 19.2363						
NUMBER OF OBSERVATIONS = 96						
SUM OF SQUARED RESIDUALS= 4708.40						
STANDARD ERROR OF THE REGRESSION = 7.15390						

VARIABLES...

OEEMM	DUMMY	RELPR	CU	HDD		
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R ²	
DUMMY	1	61.2186	10.3100	5.93778	.488043D-03	
DUMMY	2	77.2355	9.69216	7.96886	.879027D-03	
DUMMY	3	72.0424	9.09125	7.92436	.869238D-03	
DUMMY	4	77.7929	8.55897	9.08905	.114353D-02	
DUMMY	5	69.6768	8.39997	8.29489	.952425D-03	
DUMMY	6	72.5393	8.40920	8.62617	.103002D-02	
DUMMY	7	64.0975	8.44732	7.58791	.796992D-03	
DUMMY	8	65.4230	8.46559	7.72811	.826716D-03	
DUMMY	9	69.2117	8.47640	8.16523	.922882D-03	
DUMMY	10	62.0071	8.58410	7.22348	.722276D-03	
DUMMY	11	62.3875	8.99692	6.93432	.665606D-03	
DUMMY	12	58.8369	9.83448	5.98271	.495457D-03	
RELPR	1	8.51977	1.58917	5.36113	.397853D-03	
CU	1	.407184	.894081D-01	4.55422	.237104D-03	
HDD	1	-.114964D-01	.660243D-02	-1.74124	.419688D-04	
R-SQUARED = 0.8306						
R-SQUARED(COMPUTED ABOUT ZERO)= 0.9989						
R-SQUARED(CORRECTED) = 0.9987						
MULTICOLLINEARITY EFFECT= 0.9884						
DURBIN-WATSON STATISTIC= 0.9025						
F(15,82)= 26.7954						
NUMBER OF OBSERVATIONS = 96						
SUM OF SQUARED RESIDUALS= 1298.27						
STANDARD ERROR OF THE REGRESSION = 4.00350						

This regression is an indication of how important the seasonal component is in explaining the movement of a monthly output-energy ratio. The months where the intercepts are highest are April, February (probably because of the shorter length of the month), May, June, and September; the intercept is lowest for the months of December, January, October and November. All of the monthly dummy variables are significant at the 1% level. The difference between the largest and smallest is 18.9, which is more than two times the average standard deviation of about 8.9. The seasonal variation in the OER data appears to be adequately captured by this seasonal dummy variable. Note that the statistical significance of the relative price and capacity utilization variables increases as do the magnitude of these coefficients. But with the introduction of the seasonal dummies, HDD no longer enters significantly as before (although it does enter at the 10% level of confidence--a t-value greater than 1.67), and it has the correct sign. Yet this regression still has one major flaw -- the Durbin-Watson (D-W) statistic is 0.90, again indicative of strong positive serial correlation.

The regression reported on Table 5.2 re-estimates the dummy variable equation using the method of Cochrane and Orcutt to compensate for serial correlation. The parameter estimate for first order serial correlation is .586 and is significant at the 1% level of confidence. This adjustment does not alter, in any major way, the findings of the previous regression, but there are some slight difference. Although all the dummy coefficients are significant, the difference between the maximum and minimum values is now larger and the largest and smallest months have changed (February and July, respectively). The standard errors of all the variables have increased somewhat, but have little substantitive effect on our conclusions. With this correction, HDD is definitely a contributing factor to the regression, entering with the highest t-value. Stated differently, HDD now has a substantial independent explanatory effect on OER when seasonal and cyclical factors are adequately defined.

The OER (OEEMM) using the energy weighted index of output for manufacturing and mining is used to establish the structural form of the regression equation that seems adequate to explain the variation in the data. An alternative definition of the OER is next analyzed to see if these results carry over to different definitions of the dependent variable. Our second and

TABLE 5.2. Monthly Regression of OEEMM Correcting
for Serial Correlation

COCHRANE-ORCUTT ITERATIVE PROCEDURE

VARIABLES...

OEEMM DUMMY RELPR CU HDD
MEAN OF DEPENDENT VARIABLE IS 109.620
ITERATION RHO
XXXXXXXXX XXX

1 0.5842377

2 0.5859473

FINAL VALUE OF RHO= 0.5859473
NO. OF ITERATIONS= 2

STANDARD ERROR OF RHO= 0.0831400
T-STATISTIC FOR RHO= 7.0477171

INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC
DUMMY	1	72.2798	16.2911	4.43676
DUMMY	2	86.4194	15.9732	5.41028
DUMMY	3	79.0382	15.6944	5.03606
DUMMY	4	82.0920	15.4202	5.32368
DUMMY	5	71.9645	15.3674	4.68292
DUMMY	6	73.5900	15.3971	4.77948
DUMMY	7	64.8425	15.4544	4.19574
DUMMY	8	66.2290	15.4912	4.27526
DUMMY	9	70.6470	15.5284	4.54954
DUMMY	10	65.6985	15.5646	4.22103
DUMMY	11	68.6338	15.7441	4.35934
DUMMY	12	68.1681	16.1153	4.23001
RELPR	1	8.47902	3.06168	2.76940
CU	1	0.399753	0.165960	2.40873
HDD	1	-0.216923D-01	0.600567D-02	-3.61197

R-SQUARED = 0.881910

R-SQUARED(REGR SUM OF SQRS/TOTAL SUM OF SQRS)= 0.999237

R-SQUARED(CORRECTED) = 0.861244

DUREIN-WATSON STATISTIC= 2.1735

NUMBER OF OBSERVATIONS = 95

SUM OF SQUARED RESIDUALS= 877.251

STANDARD ERROR OF THE REGRESSION = 3.31144

R-SQUARED IN TERMS OF CHANGES = 0.8732

final dependent variable is OEVM: the OER constructed using the value-added weighted index of production for manufacturing and mining only.

Table 5.3 shows the same two regressions reported in Table 5.1; first the regression of OEVM against RELPR CU, and HDD, then the same regression with the seasonal intercepts. The first equation in Table 5.3 has much the same problems as its counterpart in Table 5.1. The D-W indicates that positive serial correlation of residuals exists and less than half of the total variation is explained by the independent variables. The intercept is lower in this equation, but the coefficients for RELPR and CU are higher, and somewhat more significant. In the second regression, the level of significance of the seasonal dummies is somewhat lower, and the magnitude of the two "economic" explanatory variables is somewhat higher (but consistent with somewhat lower seasonal factors). Unlike the second equation in Table 5.1, HDD is no longer a significantly explanatory variable. So we conclude that on a monthly basis there is little difference between the energy weighted and value-added weighted OERs for manufacturing and mining. Adjusting the second regression of Table 5.3 for serial correlation (shown in Table 5.4) has much the same effect for OEVM as it has for OEEM. All the explanatory variables, including HDD, are highly significant and the D-W improves to about 2.2. We note that approximately the same change occurs with the seasonal dummies.

But clearly there is a significant difference between weighting production indexes using value-added and energy-use weights. Energy price increases can bring about changes in industrial composition through substitution in the production process or through shifts from greater to lesser energy-intensive sectors. The latter could readily occur with consumption shifts resulting from changing relative prices that reflect the full cost of production. The regression results shown on Tables 5.5 and 5.6 try to measure the influence of economic and seasonal variables on this shift, as measured by the difference between the energy-use and value-added OERs.

The first regression reported in Table 5.5 has a number of significant problems, some of which we have seen before. Although the RELPR and CU variables enter the regression significantly, HDD does not. Somewhat surprisingly, the equation accounts for about 60 percent of the total variation

TABLE 5.3. Monthly Regression of OEVMH Against Three Explanatory Variables and Monthly Dummy Variables

ORDINARY LEAST SQUARES

VARIABLES...

OEVMH	#C	RELPR	CU	HDD	
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R ²
#C	1	56.4830	15.7146	3.59429	
RELPR	1	15.3994	2.93530	5.24628	.162234
CU	1	.438131	.168947	2.59330	.3964080-01
HDD	1	-.1473020-01	.2219880-02	-6.63557	.259534

R-SQUARED = 0.4577

R-SQUARED(CORRECTED) = 0.4400

MULTICOLLINEARITY EFFECT= -0.0037

DURBIN-WATSON STATISTIC= 1.2319

F(3,92)= 25.3843

NUMBER OF OBSERVATIONS = 96

SUM OF SQUARED RESIDUALS= 5290.39

STANDARD ERROR OF THE REGRESSION = 7.58316

VARIABLES...

DEVHH	DUMMY	RELPR	CU	HDD	
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R ²
DUMMY	1	37.2835	11.7030	3.18580	.1790320-03
DUMMY	2	55.6137	11.0017	5.05501	.4507510-03
DUMMY	3	50.8541	10.3196	4.92792	.4283700-03
DUMMY	4	56.4739	9.71539	5.81223	.5960280-03
DUMMY	5	49.6453	9.53491	5.20669	.4782070-03
DUMMY	6	54.7403	9.54539	5.73474	.5801220-03
DUMMY	7	45.0664	9.58865	4.69998	.3896380-03
DUMMY	8	47.6436	9.60939	4.95803	.4336210-03
DUMMY	9	53.6168	9.62166	5.57251	.5477650-03
DUMMY	10	43.8691	9.74391	4.50220	.3575550-03
DUMMY	11	41.7440	10.2125	4.08754	.2947240-03
DUMMY	12	34.9956	11.1632	3.13489	.1733560-03
RELPR	1	16.9951	1.80389	9.42138	.1565740-02
CU	1	.474180	.101488	4.67226	.3850760-03
HDD	1	-.5970720-02	.7494500-02	-.796680	.1119590-04

R-SQUARED = 0.8285

R-SQUARED(COMPUTED ABOUT ZERO)= 0.9986

R-SQUARED(CORRECTED) = 0.9983

MULTICOLLINEARITY EFFECT= 0.9917

DURBIN-WATSON STATISTIC= 0.7777

F(15,82)= 26.4152

NUMBER OF OBSERVATIONS = 96

SUM OF SQUARED RESIDUALS= 1672.79

STANDARD ERROR OF THE REGRESSION = 4.54442

TABLE 5.4. Monthly Regression of OEVMC Correcting for Serial Correlation

COCHRANE-ORCUTT ITERATIVE PROCEDURE

VARIABLES...

OEVMC DUMMY RELFR CU HDD
 MEAN OF DEPENDENT VARIABLE IS 110.164
 ITERATION RHO

1 0.6552428

2 0.6578294

FINAL VALUE OF RHO= 0.6578294
 NO. OF ITERATIONS= 2

STANDARD ERROR OF RHO= 0.0772732
 T-STATISTIC FOR RHO= 8.5130291

INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DUMMY	1	54.9015	19.7383	2.78147
DUMMY	2	70.8848	19.4595	3.64268
DUMMY	3	63.3056	19.2181	3.29407
DUMMY	4	65.3787	18.9612	3.44802
DUMMY	5	55.9074	18.9214	2.95472
DUMMY	6	59.3794	18.9581	3.13214
DUMMY	7	49.3195	19.0266	2.59213
DUMMY	8	51.9916	19.0721	2.72606
DUMMY	9	58.8162	19.1192	3.07630
DUMMY	10	52.0715	19.1464	2.71965
DUMMY	11	53.3461	19.3018	2.76380
DUMMY	12	50.6945	19.6183	2.58404
RELFR	1	16.6752	3.86955	4.30935
CU	1	0.429284	0.204218	2.10209
HDD	1	-0.195494D-01	0.628214D-02	-3.11190

R-SQUARED = 0.894703

R-SQUARED(REGRESSOR SUM OF SQUARES/TOTAL SUM OF SQUARES) = 0.999147

R-SQUARED(CORRECTED) = 0.876276

DURBIN-WATSON STATISTIC= 2.1132

NUMBER OF OBSERVATIONS = 95

SUM OF SQUARED RESIDUALS= 991.406

STANDARD ERROR OF THE REGRESSION = 3.52031

R-SQUARED IN TERMS OF CHANGES = 0.8797

TABLE 5.5. Monthly Regression of DIFF Against Three Explanatory Variables and Monthly Dummy Variables

ORDINARY LEAST SQUARES

VARIABLES...

DIFF	#C	RELPR	CU	HDD		
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R ²	
#C	1	19.3321	4.03025	4.79676		
RELPR	1	-8.85151	.752600	-11.7591	.591005	
CU	1	-.795924D-01	.433290D-01	-1.83693	.144245D-01	
HDD	1	.401738D-03	.569321D-03	.703886	.211798D-02	
R-SQUARED = 0.6067						
R-SQUARED(CORRECTED) = 0.5939						
MULTICOLLINEARITY EFFECT= -0.0008						
DURBIN-WATSON STATISTIC= 0.7227						
F(3,92)= 47.3096						
NUMBER OF OBSERVATIONS = 96						
SUM OF SQUARED RESIDUALS= 347.971						
STANDARD ERROR OF THE REGRESSION = 1.94481						
VARIABLES...						

DIFF	DUMMY	RELPR	CU	HDD		
INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T- STATISTIC	CONTRIBUTION TO R ²	
DUMMY	1	23.9351	4.07922	5.86756	.949437D-01	
DUMMY	2	21.6218	3.83477	5.63836	.876711D-01	
DUMMY	3	21.1883	3.59701	5.89053	.956887D-01	
DUMMY	4	21.3190	3.38641	6.29545	.109296	
DUMMY	5	20.0315	3.32350	6.02723	.100181	
DUMMY	6	17.7990	3.32716	5.34961	.789214D-01	
DUMMY	7	19.0311	3.34224	5.69411	.894135D-01	
DUMMY	8	17.7794	3.34946	5.30812	.777022D-01	
DUMMY	9	15.5949	3.35374	4.65000	.596290D-01	
DUMMY	10	18.1380	3.39636	5.34044	.786510D-01	
DUMMY	11	20.6434	3.55969	5.79923	.927452D-01	
DUMMY	12	23.6413	3.89107	6.12718	.103531	
RELPR	1	-8.47537	.628767	-13.4793	.501058	
CU	1	-.669952D-01	.353749D-01	-1.89386	.989118D-02	
HDD	1	-.552569D-02	.261230D-02	-2.11526	.123396D-01	
R-SQUARED = 0.7703						
R-SQUARED(COMPUTED ABOUT ZERO)= 0.7766						
R-SQUARED(CORRECTED) = 0.7380						
MULTICOLLINEARITY EFFECT= -0.8150						
DURBIN-WATSON STATISTIC= 0.3672						
F(15,82)= 18.3325						
NUMBER OF OBSERVATIONS = 96						
SUM OF SQUARED RESIDUALS= 203.226						
STANDARD ERROR OF THE REGRESSION = 1.58401						

TABLE 5.6. Monthly Regression of DIFF Correcting for Serial Correlation

COCHRANE-ORCUTT ITERATIVE PROCEDURE

VARIABLES...

DIFF DUMMY RELPR CU HDD
 MEAN OF DEPENDENT VARIABLE IS -0.544134
 ITERATION RHO
 XXXXXXXXX XXX

1 0.8371877

2 0.8424641

3 0.8437002

FINAL VALUE OF RHO= 0.8437002
 NO. OF ITERATIONS= 3

STANDARD ERROR OF RHO= 0.0550760
 T-STATISTIC FOR RHO= 15.3188276

INDEPENDENT VARIABLE	COL	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DUMMY	1	12.9604	7.54152	1.71854
DUMMY	2	11.0948	7.50864	1.47760
DUMMY	3	11.2196	7.48006	1.49994
DUMMY	4	12.1009	7.43309	1.62798
DUMMY	5	11.3482	7.43162	1.52701
DUMMY	6	9.42682	7.44562	1.26609
DUMMY	7	10.6948	7.47050	1.43160
DUMMY	8	9.38494	7.48769	1.25338
DUMMY	9	6.98209	7.50325	0.930541
DUMMY	10	8.86383	7.50238	1.18147
DUMMY	11	10.6218	7.52109	1.41227
DUMMY	12	12.9369	7.55433	1.71252
RELPR	1	-7.35364	1.88999	-3.89084
CU	1	0.146128D-01	0.781300D-01	0.187032
HDD	1	-0.255226D-02	0.147629D-02	-1.72884

R-SQUARED = 0.928636

R-SQUARED(REGR SUM OF SQRS/TOTAL SUM OF SQRS)= 0.930860

R-SQUARED(CORRECTED) = 0.916148

DURBIN-WATSON STATISTIC= 1.4878

NUMBER OF OBSERVATIONS = 95

SUM OF SQUARED RESIDUALS= 62.4198

STANDARD ERROR OF THE REGRESSION = 0.883316

R-SQUARED IN TERMS OF CHANGES = 0.7537

of the dependent variable. And the D-W statistic, at 0.72, signals strong positive serial correlation of the residuals. Reintroducing the intercept dummies improves the fit of the equation, but does little to improve the indicator of serial correlation. Again we note that this seasonal artifact raises the explanatory power of the equation to the level shown in the annual regressions--about three-fourths of the total variation is explained. The relative price and capacity variables again enter with the correct sign. RELPR is highly significant, but CU is only marginally so. Note that the size of the HDD variables improves in significance, but changes sign.

Table 5.6 repeats the second equation of Table 5.5 using the Cochrane-Orcutt procedure to correct for serial correlation. This procedure improves the fit dramatically, raising the explained variation to 92 percent, but has a number of surprises. The statistical significance of the dummy intercepts, CU and HDD are all adversely affected, with CU now clearly insignificant. And again, the D-W statistic, at 1.5, is much below its expected value of 2.0. As in previous sections, we conclude that this points to the exclusion of important explanatory variables that should be included.

5.2 SUMMARY

The main difference between an examination of annual time series and monthly data is the importance of seasonal factors in explaining month-to-month changes in both energy productivity and energy intensity in the industrial sector. Relative price remains the most significant explanatory variable of energy intensity, but monthly data highlight the important role that seasonal variables play in energy productivity measures. Cyclical variables are also important in explaining monthly energy productivity. Using annual data, CU is of marginal value as an explanatory variables; it is much more important in the monthly OER equations, but is less significant in explaining monthly differences in OERs. An important finding of both the monthly and annual analysis is that important explanatory variables are not included in this particular set of independent variables. We have suggested in the introduction what some of these variables might be. This analysis suggests, above all other conclusions, that further work is required to sort out the causes of changing energy intensity of the industrial sector.

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APPENDIX

DATA DESCRIPTION

APPENDIX: Data Description

Table A.1 tabulates the data used in the annual analysis of energy productivity. The variable labels are as follows: OEEMM is the energy weighted output index divided by energy consumption and normalized to 1967 = 100, for manufacturing and mining. OEVMM is the value-added weighted output index per unit of energy consumption, normalized so that 1967 = 100. Similarly, OEEI and OEVI are the energy and value-added output-energy ratios, respectively, for the industrial sector. RELPR is the producer price index (PPI) for fuels and power relative to the PPI for all industrial commodities; RELPR measures the price of energy relative to other industrial prices. RATIO is the proportion of producers' new durable equipment relative to the total stock of durable equipment, adjusted so that the order of magnitude is the same as that of RELPR. RATIO is an indicator of the newness and thus, we presume, the energy efficiency of capital. CU is an index of manufacturing capacity utilization. TIME and TSQ are measures of time centered about 1967.

The output per unit of energy measures were provided by R.C. Marlay (Department of Energy) and are as yet unpublished. The industrial production indexes published by the Federal Reserve Board of Governors (FRB)--approximately 135 of which are published in detail--are used to create indexes that are benchmarked to census indexes of output at the 4-digit Standard Industrial Classification (SIC) level. These revised industrial production indexes are then aggregated using either value-added or energy-use weights. The value-added weight of a particular industry is the ratio of that industry's value added relative to all the industries; similarly, for the energy weights. Thus both the value-added and energy-use weights sum to one. The base period remains 1967.

The output-energy ratios are derived by dividing each index of output by total energy consumed (in Btu's), then normalizing to an index base of 100 for 1967. The total energy series is also provided by Marlay.

The relative price of energy (PPI fuels and power/PPI industrial commodities) is based on producer price indexes published by the Bureau of Labor Statistics, U.S. Department of Labor. The capacity utilization index is

TABLE A.1. Revised Variables Used in Annual Marlay Regressions

YRS	DEEMM	DEVMM	DEEI	DEVI	RELPR	RATIO	CU	TIME	TSQ
XXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX
1954	89.8	89.1	93.3	93.4	1.07	1.76	80.1	-13	169
1955	92.7	88.5	95.1	92.1	1.05	1.79	87.0	-12	144
1956	92.3	88.2	94	90.5	1.04	1.79	86.1	-11	121
1957	91.6	88.7	94.2	91.6	1.06	1.80	83.6	-10	100
1958	89.7	86.7	92.6	90.1	1.02	1.84	75.0	-9	81
1959	95.5	92.1	96.6	94.1	1.00	1.87	81.6	-8	64
1960	93.7	90.0	94	91	1.01	1.89	80.1	-7	49
1961	94.2	89.5	94.5	91	1.03	1.92	77.3	-6	36
1962	96.5	92.8	96.3	93.8	1.02	1.93	81.4	-5	25
1963	97.6	93.5	97.6	94.7	1.02	1.92	83.5	-4	16
1964	98.8	93.4	97.8	93.8	.98	1.90	85.7	-3	9
1965	101.8	98.2	101	98.5	.99	1.85	89.5	-2	4
1966	102.1	100.8	100.5	99.5	.99	1.80	91.1	-1	1
1967	100.0	100.0	100	100	1.00	1.76	86.9	0	0
1968	100.6	100.6	100.7	100.7	.96	1.76	87.0	1	1
1969	102.1	100.2	101.5	99.4	.95	1.76	86.2	2	4
1970	98.6	94.4	98	93.8	.97	1.77	79.2	3	9
1971	99.8	95.8	100.1	96.3	1.01	1.78	78.0	4	16
1972	103.5	100.3	103.3	100.3	1.01	1.79	83.1	5	25
1973	105.5	103.3	104.8	102.1	1.07	1.78	87.5	6	36
1974	107.7	105.2	106.1	102.2	1.35	1.76	84.2	7	49
1975	103.7	103.1	103.6	100.6	1.43	1.75	73.6	8	64
1976	108.3	107.2	107.9	104.2	1.46	1.76	80.2	9	81
1977	110.4	111.3	109.8	107.7	1.55	1.75	82.4	10	100
1978	115.1	116.7	114.2	112.8	1.54	1.75	84.2	11	121
1979	117.0	120.0	110.2	109.5	1.73	1.75	85.6	12	144
1980	115.8	120.9	108	108.8	2.09	1.76	79.8	13	169

taken directly for FRB publications and is based on the same FRB indexes of industrial production used to construct the indexes of industrial production used in this study. The ratio of new equipment to the stock of equipment is based on the Census of Manufacturers and the Annual Survey of Manufacturers equipment purchases and equipment stocks extended to 1980 based on National Income and Product Account estimates of manufacturing equipment expenditures. The bureaus responsible for generating these figures within the Department of Commerce are Bureau of the Census and Bureau of Economic Analysis, respectively.

The monthly data used in Section 5.0 are shown in Table A.2. IPVMM and IPEMM are the industrial production indexes for manufacturing and mining; the first is the value-added weighted index, the second the Marlay index. ENGY is the monthly industrial use of energy in Btu's. OEVMM, OEEMM, RELPR and CU are as previously defined, but now reported on a monthly basis. One addition, heating degree days (HDD), deserves a reference, while a deletion, the ratio of new to total capital equipment, results from the lack of monthly data for this series. Heating degrees days are measures of the period within a month during which temperatures fell below a norm (65 degrees in this case), requiring home heating. Since the deviation from the norm is used as a weighting factor, more severe cold weather will indicate the need for more heating. Thus, the use of HDD in a monthly analysis should account for both severe weather energy demand shifts and the seasonal use of industrial heating as it affects energy consumption. The HDD data are provided by the National Oceanographic and Atmospheric Agency (NOAA).

TABLE A.2. Revised Variables Used in Monthly Marlay Regressions
November 1982

MONTHS	IFUMM	IFEMM	ENGY	CEEMM	CEUMM	SELER	CU	FOO
XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX	XXXXXX	XXXXXX	XXXX	XXXX
73.01	119.4	122.8	2597	94.269	91.614	1.0183	86.5	913
73.02	125.3	127	2342	108.11	106.51	1.0387	87.5	795
73.03	126.4	128.1	2376	107.48	106.01	1.0326	87.7	515
73.04	126.3	129.3	2391	107.81	105.26	1.0595	87.4	564
73.05	127.4	131	2464	105.99	103.03	1.0771	87.9	190
73.06	130.4	132.1	2301	114.45	112.93	1.1253	87.2	22
73.07	122.5	127.1	2309	109.74	105.72	1.1253	88	6
73.08	126.8	130.8	2417	107.89	104.54	1.1217	87.6	8
73.09	131.8	131.9	2312	113.74	113.6	1.0726	87.8	63
73.10	132.7	134.1	2584	103.46	102.33	1.034	87.7	217
73.11	130.4	132.5	2448	99.756	98.13	1.1376	87.7	510
73.12	123.2	127.9	2733	93.298	99.828	1.146	87.3	820
74.01	122.9	126.5	2446	103.1	100.12	1.201	85.8	862
74.02	126.8	128	2338	109.15	108.07	1.2336	85.3	777
74.03	128	130.1	2386	108.71	106.9	1.3272	85.4	575
74.04	127.4	131.5	2195	119.44	115.66	1.3499	85.1	316
74.05	129	133	2314	114.59	111.09	1.3575	85.6	176
74.06	132.2	135	2221	121.18	118.61	1.3704	85.7	44
74.07	123.5	128.4	2350	108.93	104.72	1.4149	85.4	6
74.08	127.5	130.4	2398	108.41	105.95	1.3985	85.1	13
74.09	132.1	131.9	2392	109.93	110.05	1.3912	84.8	100
74.10	130.4	132.4	2597	101.64	100.06	1.3965	82.9	314
74.11	122.4	125.2	2570	97.121	94.905	1.3715	79.5	538
74.12	110.5	115.6	2539	90.769	86.724	1.3787	75.1	813
75.01	107.4	112.8	2539	88.571	84.291	1.3863	71.9	843
75.02	108.8	112.6	2105	106.64	103	1.3795	70.1	764
75.03	107.7	110.5	2222	99.143	96.586	1.3714	69	708
75.04	109.4	111.3	1906	116.42	114.38	1.3936	69.9	459
75.05	110.6	111	1969	112.39	111.93	1.4122	70.3	118
75.06	115.5	113.3	2304	113.21	114.35	1.4236	71.9	36
75.07	109.9	139.4	2080	104.36	105.29	1.4404	73.3	5
75.08	117.1	115.6	2166	106.4	107.73	1.4657	74.8	12
75.09	122.4	119.6	2134	111.73	114.3	1.4726	75.7	106
75.10	122.7	121.4	2402	100.76	101.79	1.4682	75.5	241
75.11	120.7	120.7	2401	100.22	100.17	1.4652	76.2	471
75.12	115.8	117.2	2581	90.528	99.405	1.4651	76.6	826
76.01	117.7	118.3	2478	95.176	94.649	1.4512	77.5	1003
76.02	124.9	125	2143	116.29	116.14	1.4365	78.8	627
76.03	125.7	127.1	2233	113.47	112.17	1.4293	79	560
76.04	126	129.4	2113	122.09	118.93	1.4272	79.1	314
76.05	127.7	130.6	2298	117.92	115.25	1.4257	79.6	185
76.06	130.9	132.7	2212	119.6	117.92	1.4357	79.7	27
76.07	122.7	125.8	2274	110.29	107.52	1.4513	80.1	3
76.08	128.5	130.6	2309	112.76	110.9	1.4646	80.1	18
76.09	131.9	130.8	2246	116.1	116.94	1.4675	79.8	85
76.10	132.1	131.7	2615	100.41	100.66	1.4874	79.5	382
76.11	129.9	129.9	2630	98.468	98.422	1.5051	80.1	691
76.12	125	125.4	2765	90.416	90.086	1.4968	80.5	970

TABLE A.2. (Contd)

MONTHS	IFVMM	IFERM	ENGY	DEEMM	DEVMM	RELPR	CU	HDD
XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXX	XXXXXX	XXXXX	XXXXX
77.01	125.1	123.9	2630	93.9	94.8	1.4793	80.2	1224
77.02	130.6	129.1	2047	125.7	127.1	1.5219	80.4	776
77.03	133.3	133.8	2357	113.2	112.7	1.5321	81.5	542
77.04	134.2	136.1	2213	122.6	120.8	1.5458	81.7	276
77.05	135.4	137.8	2398	115.0	113.0	1.5566	82.1	118
77.06	139.4	138.7	2370	116.7	117.2	1.5622	82.4	38
77.07	130.7	131.6	2341	112.1	111.3	1.5659	82.5	5
77.08	135.8	134.8	2395	112.2	113.0	1.5719	82.4	14
77.09	140.6	134.9	2414	111.4	116.1	1.5657	82.4	61
77.10	141.9	137.9	2542	108.2	111.2	1.56	82.6	306
77.11	138.3	135.1	2601	103.6	106.0	1.558	82.5	508
77.12	132.6	131.1	2728	95.8	96.9	1.56	82.6	871
78.01	130.7	129.7	2706	95.6	96.2	1.5516	81.7	1094
78.02	136.2	131.9	2238	117.5	121.3	1.5421	81.7	989
78.03	138.9	135.7	2242	120.7	123.5	1.5448	82.7	703
78.04	142.7	141.2	2243	125.5	126.8	1.5403	83.8	359
78.05	142.5	143.1	2408	118.5	117.9	1.5415	83.8	162
78.06	147.1	145.9	2318	125.5	126.5	1.5486	84.3	31
78.07	138.7	139.0	2396	115.7	115.4	1.5438	84.8	8
78.08	145.0	142.6	2411	117.9	119.8	1.5369	85.2	11
78.09	150.9	145.7	2357	123.4	127.6	1.5374	85.5	61
78.10	152.4	147.8	2579	114.3	117.8	1.53	86.0	295
78.11	149.5	146.9	2637	111.1	113.0	1.5264	86.3	531
78.12	144.8	144.3	2782	103.4	103.7	1.5391	86.8	867
79.01	141.9	138.5	2919	94.6	96.9	1.5368	86.6	1109
79.02	148.2	142.2	2480	114.3	119.1	1.5393	86.8	981
79.03	151.2	146.3	2533	115.1	118.9	1.5571	87.2	593
79.04	148.3	147.9	2391	123.3	123.6	1.5831	85.3	375
79.05	150.5	148.0	2581	114.3	116.2	1.6326	86.3	154
79.06	154.6	150.4	2497	120.1	123.4	1.6825	86.1	38
79.07	145.4	143.7	2530	113.2	114.5	1.7346	86.0	7
79.08	150.0	146.9	2582	113.4	115.8	1.7988	84.9	15
79.09	155.6	148.0	2477	119.1	125.2	1.8624	85.2	62
79.10	156.1	148.8	2766	107.2	112.5	1.8695	84.8	282
79.11	152.2	147.6	2783	105.7	109.0	1.8842	84.4	542
79.12	146.3	144.5	2856	100.9	102.1	1.8722	84.1	770
80.01	142.8	141.7	2892	97.7	98.4	1.9105	84.0	914
80.02	148.1	144.2	2592	110.9	113.9	1.9832	83.6	860
80.03	149.1	145.3	2636	109.9	112.7	2.0447	82.7	702
80.04	144.7	142.1	2347	120.7	122.9	2.0881	80.3	348
80.05	140.7	136.8	2407	113.3	116.5	2.0949	77.6	145
80.06	142.0	135.0	2306	116.7	122.7	2.0656	75.7	50
80.07	132.8	124.6	2268	109.5	116.7	2.1042	74.9	5
80.08	140.0	129.6	2216	116.6	125.9	2.1134	75.8	9
80.09	147.4	135.6	2338	115.6	125.6	2.1046	77.0	56
80.10	150.7	140.9	2629	106.8	114.2	2.0921	78.2	329
80.11	150.6	143.3	2679	106.6	112.0	2.0942	79.3	581
80.12	146.7	141.8	2818	100.3	103.7	2.1122	79.8	858

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